2. Soil Degradation and Global Food Security: A Soil Science Perspective

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Arable land area per capita is declining on a global scale because of population growth, conversion of agricultural land to other uses, and soil degradation. The world's population grew from about 0.6 billion people in 1700 to 6.0 billion people in 2000. Over the same period, the world's arable land area grew only half as fast, from 0.3 billion hectares to 1.5 billion hectares. Consequently the mean arable land area per capita decreased from 0.5 hectares in 1700 to 0.25 hectares in 2000 for the world as a whole, and many densely populated countries average 0.1 hectares (or less) of arable land per capita (Engelman and LeRoy 1995). The minimum land area required for meeting basic necessities of life, even with adoption of recommended agricultural practices, has been estimated to be about 0.07 hectares per capita (Buringh et al. 1976). By this standard, a significant share of the world's population will be prone to land scarcity in the coming decades (Table 2.1). The number of people dependent on less than 0.07 hectares per capita is projected to range between 1.4 billion and 4.7 billion in 2050, depending on future population growth rates (Engelman and LeRoy 1995).

These projections are based on the assumption that total arable land area will remain constant over the next five decades. Yet the area available for agriculture is progressively declining because of soil degradation and conversion to other land uses, including urbanization. The best available data indicate that about 15 percent of the world's land area currently suffers from soil degradation (Table 2.2). The extent and severity of soil degradation are especially high in the developing countries of the tropics and sub-tropics.

Soil degradation is an important factor to consider when assessing the world food situation (Scherr 1999; Oldeman 1998; Pinstrup-Andersen et al. 1997). Soil degradation can adversely impact food security by reducing agronomic productivity, especially in regions with resource-poor farmers who cannot afford to apply inputs at recommended levels (Scherr 1999; Oldeman 1998; Lal 1998). The adverse impacts of soil degradation on agronomic productivity and food security are compounded and exacerbated by the scarcity of water for agriculture. The number of water-scarce countries is projected to

Table 2.1 Global estimates of the land-scarce population (billions)

Year	Low projection	Medium projection	High projection
1990	0.3	0.3	0.3
2000	0.3	0.3	0.4
2010	0.5	2.0	2.1
2020	0.8	2.3	2.4
2030	1.0	2.8	3.5
2040	1.4	3.5	4.2
2050	1.4	3.8	4.7

Note: Land scarcity is defined as having less than 0.07 hectares per person.

Source: Recalculated from Engelman and LeRoy (1995).

grow from 20 in 1990 to 30–35 by 2025, while the number of people living in water-scarce countries is projected to increase from 0.1 billion to 0.8–1.1 billion over the same period (Engelman and LeRoy 1993).

SOIL DEGRADATION

In the soil science and agronomy literature, the term 'soil degradation' denotes a decline in soil quality as a result of anthropogenic factors. (By contrast, land degradation encompasses changes in climate, vegetation, and hydrology as well as soil, and desertification refers to land degradation in arid and semi-arid climates.) The concept of soil quality is, in turn, based on the soil's capacity to produce biomass and perform environmental services. Despite the importance of soil quality, definitions generally remain vague, qualitative, and subjective. Therefore, improved estimates of soil degradation can only be obtained by defining soil quality in precise, objective, quantitative terms, and by developing standardized methods to assess soil quality under different land uses and management practices.

Soil degrades as a result of physical, chemical, and biological processes (Figure 2.1). Soil physical processes are set in motion by decline in soil structure and reduction in magnitude and strength of aggregates, caused by inappropriate or excessive plowing and reduction in soil organic matter content. Decline in soil structure accentuates soil's susceptibility to crusting, compaction, and accelerated runoff and erosion. Soil chemical degradation is caused by depletion of bases (such as calcium and magnesium) as a result of leaching (leading to reduction in soil pH or acidification), by

Table 2.2 Estimates of the global extent of soil degradation by different processes (million hectares unless otherwise noted)

Region	Total land area	Total degraded area	Total degraded area (%)	Water erosion	Wind erosion	Physical degradation	Chemical degradation
Africa	2,964	494	17	227	186	19	62
Asia	3,085	749	24	441	222	12	74
S. America	1,753	243	14	123	42	8	70
C. America	108	63	58	46	5	5	7
N. America	2,029	96	5	60	35	1	—
Europe	2,260	218	10	114	42	36	26
Oceania	849	102	12	83	16	2	1
World	13,048	1,965	15	1,094	548	83	240

Note: North America consists of the United States, Canada, and Mexico.

Sources: Modified from Oldeman (1994), land area from FAO (1998).

accumulation of salts in the root zone as a result of impeded drainage or excessive irrigation in soils of arid and semi-arid regions through processes of salinization or alkalization, and by depletion of plant nutrients (such as nitrogen, phosphorus, potassium, zinc, and copper). Soil biological degradation is caused by reduction in the quantity and quality of soil organic matter content, with attendant decline in activity and species diversity of soil fauna.

All three processes are interactive; each exacerbates the rate and impact of the others, adversely affecting agronomic yields and biomass production. Reductions in plant growth and biomass production further accentuate the rate and severity of degradative processes. In addition, soil degradation has strong adverse impacts on water quality and emission of greenhouse gases (such as carbon dioxide, methane, and nitrous oxide) into the atmosphere.

THE EXTENT OF SOIL DEGRADATION

Estimates of the extent and severity of soil degradation vary widely at regional and global scales, due in part to differences in the criteria used to define, and methods used to assess, soil degradation. In addition to showing the total

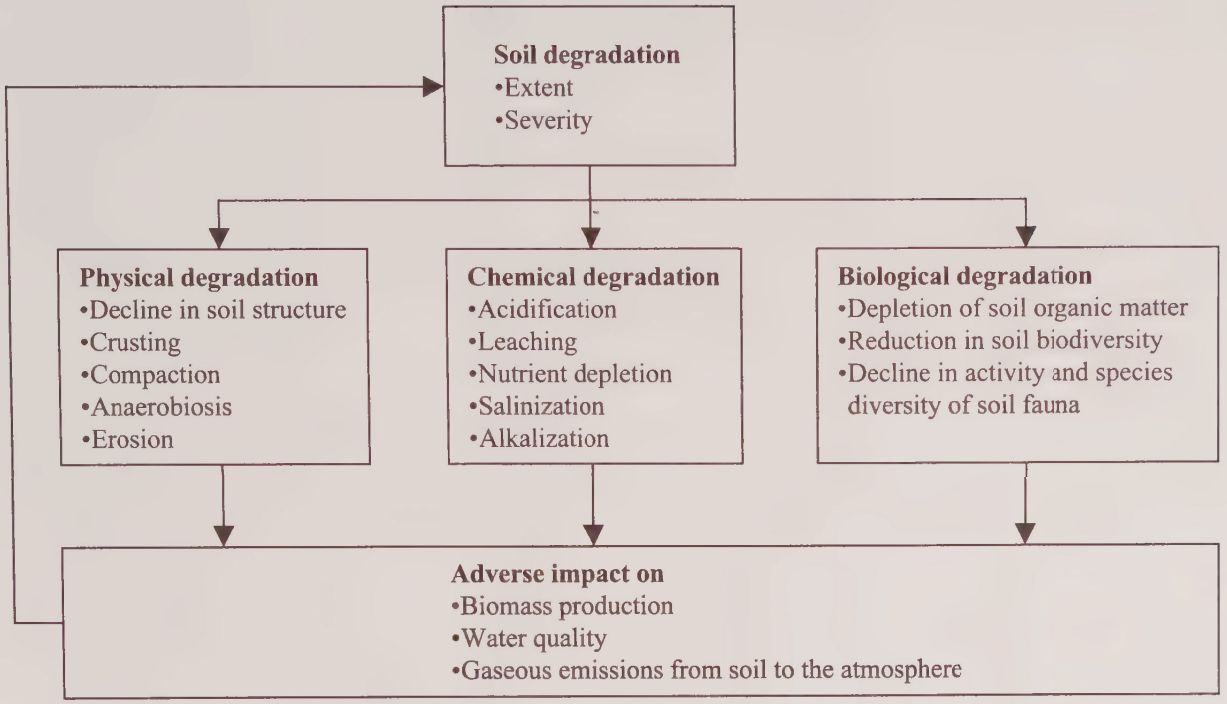

Figure 2.1 Soil degradation processes and their impact on biomass production and environment quality

extent of soil degradation by region, Table 2.2 provides estimates of soil degradation by different processes at regional and global scales from the Global Assessment of Soil Degradation (GLASOD) by Oldeman et al. (1990). Land areas affected by different soil degradation processes since the middle of the 20th century include 1,094 million hectares by water erosion, 548 million hectares by wind erosion, 240 million hectares by chemical degradation, and 83 million hectares by physical degradation. Chemical degradation includes a wide variety of processes such as loss of plant nutrients and depletion of soil fertility, salinization/alkalization, pollution/contamination, and acidification. Physical degradation includes crusting and surface sealing, compaction, waterlogging, and anaerobiosis. Accelerated erosion by water and wind are also forms of physical degradation.

Water Erosion

Large areas susceptible to water erosion occur in tropical and sub-tropical regions of Asia, Africa, and Latin America. Particularly susceptible are areas of sloping land and semi-arid regions with monsoonal rains. Global hot spots of water erosion include the Himalayan–Tibetan ecosystem, the Andean region, the Caribbean, the Loess Plateau in China, and some regions of western Africa (Scherr and Yadav 1996). Of the 1,094 million hectares affected by water erosion worldwide, 223 million hectares (20 percent) are strongly or extremely affected and 526 million hectares (48 percent) are moderately affected; the remaining 345 million hectares (32 percent) are lightly affected (Oldeman 1994). Whereas the factors affecting water erosion (such as rainfall and runoff energy, slope gradient, and soil erodibility) are well established, the causes of water erosion differ among ecoregions. Principal causes of water erosion in many regions include deforestation, biomass burning, plowing, and over-grazing.

Wind Erosion

Large areas with arid and semi-arid climates are prone to accelerated wind erosion. Some soils in semi-arid regions are affected by water erosion during the rainy season and wind erosion during the dry season. Like water erosion, wind erosion is most severe in Asia, Africa, and Latin America. Of the 548 million hectares affected by wind erosion worldwide, 26 million hectares (5 percent) are strongly/extremely affected, 254 million hectares (46 percent) are moderately affected, and the remaining 269 million hectares (49 percent) are lightly affected. Because rangeland is the predominant land use in arid and semi-arid regions, over-grazing is the principal cause of wind erosion.

Soil Fertility Decline and Salinization

Areas in which more nutrients are removed in harvested products than are replaced by applications of organic amendments and inorganic fertilizers are characterized by negative nutrient balances and declining soil fertility. The problem of soil fertility decline is most severe in Sub-Saharan Africa and elsewhere in the tropics where subsistence agriculture is widely practiced by resource-poor farmers. About 136 million hectares (about 10 percent of the world's total cropland area) are affected by soil fertility decline (Oldeman 1994). An important environmental ramification of soil fertility decline is the depletion in soil organic matter content. Fertility-depleting agricultural practices exacerbate the rate of mineralization of soil organic matter content, leading to emission of the greenhouse gases carbon dioxide (under aerobic conditions) and methane (under anaerobic conditions).

Secondary (i.e., anthropogenic) salinization is caused by excessive irrigation, lack of internal drainage, and use of brackish or poor quality water. (In contrast, primary salinization is caused by natural soil-forming factors such as high salt content in the parent material.) Secondary salinization affects about 77 million hectares of irrigated land worldwide, of which 53 million hectares (69 percent) are in Asia (especially India, China, Pakistan, and Iran) (Oldeman 1994). Risks of salinization can be minimized by appropriate use of irrigation and appropriate provisions for drainage.

Decline in Soil Structure and Compaction

Decline in soil structure is caused by excessive plowing, complete removal of crop residues, and insufficient use of organic amendments and biosolids. Depletion of soil organic matter content exacerbates the extent and severity of decline in soil structure. Important ramifications of decline in soil structure include susceptibility to crusting and surface sealing, and compaction or densification. Soil compaction affects 68 million hectares of land worldwide, of which 33 million hectares (49 percent) are in Europe (Oldeman 1994).

Regional Hot Spots of Soil Degradation

The GLASOD methodology was also used to estimate the extent of soil degradation in seven countries of South Asia. The data in Table 2.3 show that 34 percent (18 million hectares) of the total land area in these countries suffers from soil degradation. Of these 218 million degraded hectares, 82 million hectares (38 percent) suffer from water erosion, 59 million hectares (27 percent) from wind erosion, and 42 million hectares (19 percent) from salinization

Table 2.3 Extent of soil degradation in South Asia (million hectares)

Country	Total area	Cropland area	Pasture area	Extent of soil degradation						
				Water erosion	Wind erosion	Water-logging	Fertility decline	Salini-zation	Lowering of water table	Total
Afghanistan	65.2	8.1	30.0	11.2	2.1	0.0	0.0	1.3	0.0	14.6
Bangladesh	13.0	9.1	0.6	1.5	0.0	0.0	6.4	0.0	0.0	7.9
Bhutan	4.7	0.1	0.3	0.04	0.0	0.0	0.0	0.0	0.0	0.04
India	297.3	169.1	12.1	32.8	10.8	3.1	3.2	4.1	0.2	54.0
Iran	163.6	15.1	44.0	26.4	35.4	0.6	0.0	32.7	19.5	114.6
Nepal	13.7	2.7	2.0	1.6	0.0	0.0	0.0	0.0	0.0	1.6
Pakistan	77.1	20.8	5.0	7.2	10.7	1.0	0.0	3.8	0.1	22.8
Sri Lanka	6.5	1.9	0.4	1.1	0.0	0.0	1.4	0.05	0.0	2.5
Total	641.1	226.7	94.4	81.8	59.0	4.7	11.0	41.9	19.6	218.0

Source: Modified from FAO (1994 and 1998).

Table 2.4 Estimates of irrigated saline soils in Central Asia (million hectares)

Country	Total land area	Total irrigated area	Saline irrigated area
Turkmenistan	48.8	1.2	1.1
Uzbekistan	44.9	4.1	2.1
Tadjikistan	14.3	0.7	0.1
Kyrgyzstan	271.5	1.0	0.1
Total	379.5	7.1	3.5

Source: Modified from Esenov and Redjepbaev (1999).

(Table 2.3). Large areas of sloping lands are severely affected by water erosion in India, Iran, Afghanistan, and Pakistan. The problems of salinization and lowering of water tables are exacerbated by excessive irrigation due in part to subsidies for water and electricity and a lack of incentives for appropriate water use.

Secondary salinization is also a severe problem in four countries of Central Asia. Of the total irrigated area of 7.1 million hectares in these four countries, 3.5 million hectares (49 percent) are severely affected by salinization (Table 2.4). Excessive use of irrigation, inadequate internal drainage, and use of poor quality water have contributed to the problem.

DESERTIFICATION

Desertification, the process of soil and vegetation degradation in dry climates, is caused by anthropogenic factors. Desertification leads to decline in the productivity of plants and animals, and is also a major factor in the decline of biodiversity. The process of desertification is accelerated by water and wind erosion, salinization, fertility depletion, and compaction. The principal causes of desertification are over-grazing, denudation of vegetation, conversion to inappropriate land use, and widespread adoption of inappropriate management practices.

As in the case of soil degradation, credible estimates of land area prone to and affected by desertification are scarce (Lal et al. 1999). Using the GLASOD methodology, Oldeman and Van Lynden (1998) estimated the extent of soil degradation in arid regions to be 1,137 million hectares, of which 48 million hectares were moderately or strongly degraded. UNEP (1991) estimated that 1,016 million hectares of land area were affected by soil degradation and an

Table 2.5 Estimates of the global extent of desertification (million hectares unless otherwise noted)

Region	Irrigated land	Rainfed cropland	Range-land	Total desertified area	Total land area	% of area desertified
Africa	1.9	48.9	995.1	1,045.8	1,432.6	73
Asia	31.8	122.3	1,187.6	1,341.7	1,881.4	71
Aust. and NZ	0.3	14.3	361.4	375.9	701.2	54
Europe	1.9	11.9	80.5	94.3	145.6	65
N. America	5.9	11.6	411.2	428.6	578.2	74
S. America	1.4	6.4	297.8	305.8	420.7	73
World	43.2	215.8	3,333.5	3,592.1	5,159.7	70

Source: Modified from Dregne and Chou (1992).

additional 2,576 million hectares were affected by vegetation degradation. UNEP (1991) thus estimates that the total area affected by desertification was 3,592 million hectares or 70 percent of the global total land area in arid, semi-arid and sub-humid regions. Table 2.5 disaggregates this estimate by continent and land use. Of the total desertified area of 3,592 million hectares, 3,334 million hectares (93 percent) are rangeland, while 43 million hectares (1.2 percent) are irrigated land and 216 million hectares (6 percent) are rainfed cropland. About 37 percent (1,342 million hectares) of the total desertified area is in Asia and 29 percent (1,046 million hectares) is in Africa (Table 2.5). Estimates of the rate of desertification range from 4 to 6 million hectares per year (UNEP 1991).

Numerous hot spots can be found around the world, but desertification is a particularly serious problem in Central Asia. Table 2.6 presents estimates of land area affected by desertification in that region, including 63 million hectares in Kazakhstan, 28 million hectares in Turkmenistan, and 16 million hectares in Uzbekistan. The lowering of the water level in the Aral Sea (due to increased diversion for agricultural and industrial uses) is an important causative factor in the spread of desertification in general and salinization in particular.

AGRONOMIC AND ENVIRONMENTAL EFFECTS OF SOIL DEGRADATION AND DESERTIFICATION

Soil degradation and desertification affect productivity on-site as well as environmental quality off-site (Scherr 1999). Desertification control and restoration

Table 2.6 Estimates of the extent of desertification in Central Asia (million hectares)

Country	Vegetation degradation	Water erosion	Wind erosion	Salinization of cropland	Salinization by sea level lowering	Technological desertification	Total area
Kazakhstan	48.2	na	na	0.7	7.5	6.1	63.2
Uzbekistan	4.7	na	1.1	0.4	0.8	4.2	16.3
Turkmenistan	12.6	1.2	4.8	2.1	1.2	1.2	27.7
Total	65.5	1.2	5.9	3.2	9.5	11.5	107.2

Note: "na" = not available.

Source: Modified from Babaeva (1999).

of degraded soils worldwide are thus important strategies to enhance biomass production and improve environmental quality.

Especially important among the adverse off-site environmental impacts are pollution or contamination of natural waters and emission of trace or greenhouse gases into the atmosphere. Emission of greenhouse gases by desertification results from the depletion of soil organic matter content and an overall decline in soil quality. Accelerated soil erosion and exploitative systems of subsistence agriculture exacerbate the emission of carbon dioxide from soil and terrestrial ecosystems. Lal et al. (1999) estimated that erosion in arid and semi-arid regions leads to emission of 230 to 290 million metric tons of carbon per year.

With regard to the on-site productivity effects of soil degradation and desertification, erosion-induced losses are among the most significant and have received the most attention. While erosion's effects on crop yields and agricultural production have been described elsewhere (Lal 1998 and 2001; den Biggelaar et al. 2001; see also Chapter 12 in this volume), the on-site costs of soil compaction have received relatively little attention.

Soil Compaction and Agronomic Productivity

Soil compaction is caused by a high frequency of wheel traffic by heavy machinery (Lull 1959), and also by the treading of working and grazing animals. Soil compaction is especially severe in clayey soils with slow internal drainage and with structurally inert properties. The latter are soils of low-activity clays containing low organic matter content and low shrink–swell capacity. In this regard, soils of the tropics and sub-tropics are more prone to

sub-soil compaction than soils of the temperate/boreal climates. It is estimated that more than 30 million hectares of farmland in Europe and 80 million hectares worldwide are severely degraded by sub-soil compaction (Soane and Van Ouwerkerk 1994).

Various mechanisms are responsible for the adverse effects of soil compaction on plant growth and environment. Plant growth is adversely affected by reductions in root growth, water infiltration in the soil, aeration or gaseous diffusion between the soil and the atmosphere (Flowers and Lal 1998), and nutrient uptake (Figure 2.2). When soil compaction restricts root growth, the efficiency of water and nutrient uptake is much reduced, and crop yields are adversely affected.

Several models have been proposed to assess yield losses by soil compaction (Arvidsson et al. 2000). Because of the lack of precise understanding of soil processes, however, most of these models are based on statistical relationships rather than conceptual or theoretical understanding. For example, Arvidsson and Håkansson (1991) developed a model to predict the effects of sub-soil compaction (indicated by soil clay content, soil water content at the time of the traffic, axle load, and machinery width) on yield losses in sugar beets at the farm level in Sweden. Simota et al. (2000) developed a simulation model for soil water dynamics and crop yield formation (SIBIL) to assess soil compaction's effects. They observed a strong correspondence between simulated and experimental yields of barley and corn in Poland and Romania, and found that most of the crop yield changes due to soil compaction were related to bulk density. Trautner et al. (2000) developed a strong database for assessing the impact of soil compaction in Europe, and there are numerous empirical/experimental examples of the adverse effects of soil compaction on yield of crops in temperate regions (Soane and Van Ouwerkerk 1994; Voorhees 2000; Alakukku 2000; Hernanz and Sanchez-Girón 2000; Horn et al. 2000).

Mechanized farming operations are also leading to severe compaction in soils of the tropics (Kayombo and Lal 1994), but no such modeling attempts have been made for tropical soils and crops, and research on the magnitude of yield reduction by compaction in tropical areas remains scarce. Soil-compaction experiments in Pakistan showed significant reductions in grain yield of wheat and biomass yield of sorghum fodder (Table 2.7). The adverse effects on crop growth and yield were due in part to reduced uptake of essential nutrients (Ishaq et al. 2001b). The greatest yield reductions occurred in the first year after compaction: the reduction in wheat grain yield was 38 percent in the first year compared with 8 percent in the second year following the compaction. Similarly, the reduction in sorghum fodder was 22 percent in the first year compared with 14 percent in the second year following compaction. Nevertheless, compaction's adverse effects are not limited to the short term; Lal (1996) observed that adverse effects of compaction on a crop

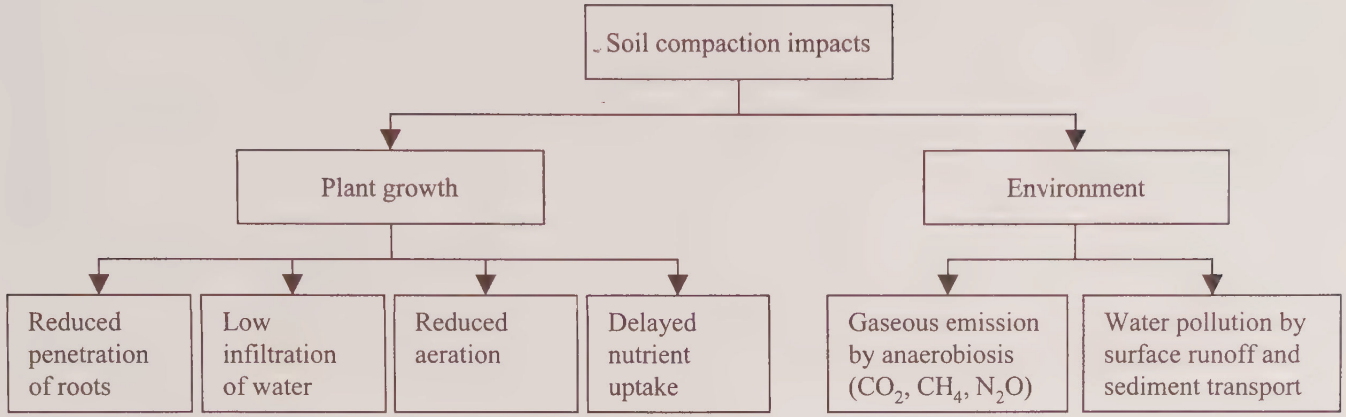

Figure 2.2 Processes governing compaction effects on plant growth and environment

Table 2.7 Yield of wheat and sorghum as affected by sub-soil compaction in Punjab, Pakistan

	Wheat grain (kg/ha)		Sorghum biomass (Mg/ha)	
Treatment	1997–1998	1998–1999	1997–1998	1998–1999
Compacted	2,335	3,145	23.1	35.8
Control	3,779	3,429	29.6	41.7
Least Significant Difference (.05)	421	153	1.7	1.6

Source: Adapted from Ishaq et al. (2001a).

yield in a clayey soil in Ohio persisted for seven years following harvest traffic of 10 to 20 tons per axle.

Adverse effects of simulated harvest traffic on yield of cassava tubers grown on an Alfisol in western Nigeria are shown in Table 2.8. Reduction in cassava yield was greater with a no-till method of seedbed preparation than with plow-till seedbed preparation. In no-till, cassava tuber yield declined by 11 percent with two passes and 47 percent with four passes of a two-ton roller. In plow-till, cassava tuber yield declined by 38 percent with four passes, although there was a slight increase (12 percent) with two passes of the roller (Kayombo et al. 1986). Drastic compaction-induced reductions in yields of maize, cowpeas, and soybeans (Kayombo and Lal 1986) were due to adverse effects on yield components such as grains per cob in maize, grains per plant in cowpeas, and unit grain weight in soybeans (Table 2.9). In contrast to cassava tubers, the magnitude of reductions in yield components of grain crops was more drastic in the plow-till than the no-till method of seedbed preparation. The reduction with four passes of the roller was 49 percent in no-till versus 62 percent in plow-till for grains per cob in maize, 36 percent in no-till versus 53 percent in plow-till for grains per plant in cowpeas, and 40 percent in no-till versus 54 percent for plow-till in unit grain weight in soybeans.

PREVENTION VERSUS RESTORATION OF SUB-SOIL COMPACTION

Sub-soil compaction can be caused by numerous factors, including heavy loads in the form of machinery and cattle traffic, the smearing effect of a plow share traversing repeatedly at the same depth, and soil properties that lead to

Table 2.8 Response of cassava tubers to soil compaction in western Nigeria (tons per hectare)

Number of passes of the roller	No-till	Plow-till
0	18.4	20.6
2	16.3	24.1
4	9.7	12.7
Least Significant Difference (.05)	3.1	

Source: Adapted from Kayombo et al. (1986).

densification. In addition to tillage and harvesting traffic, soil compaction in newly cleared land can also be caused by heavy machinery used for deforestation and land clearing. Experiments conducted in Nigeria (Lal 1981 and 1984; Hulugalle et al. 1984) showed severe yield reductions following mechanized clearing compared with manual clearing (Table 2.10). The global average rate of tropical deforestation is estimated at 15 to 20 million hectares per year, most of which are cleared by heavy machinery leading to scraping away of the surface soil and severe compaction of the sub-soil. Lal et al. (1981) recommended that if deforestation is inevitable, it should be done either manually or with the shear blade method. (The shear blade, mounted in front of a crawler tractor, cuts the trees at ground level without removing the roots. Soil disturbance, if any, is minimal.) Further, newly cleared land should be sown to a restorative cover crop with deep tap roots to alleviate sub-soil compaction. Macropores created by earthworm activity can also alleviate soil compaction and improve soil structure (Larink and Schrader 2000).

Table 2.9 Response of grain crops to soil compaction in Nigeria

Number of passes of the roller	Maize (grains/cob, g)		Cowpea (grains/plant)		Soybean (100 grain weight, g)	
	No-till	Plow-till	No-till	Plow-till	No-till	Plow-till
0	117.9*	156.3*	18.2	19.3	36.1	32.4
2	75.3	79.7	14.3*	11.3*	25.5*	20.9*
4	60.4	58.8	11.6*	9.0*	21.7*	14.9*

Note: Means followed by an asterisk are significantly different at $P_{0.05}$.

Source: Adapted from Kayombo and Lal (1986).

Table 2.10 Soil compaction effects on crop yield in Nigeria and Pakistan

Cause of soil compaction	Country	Crop	Yield decline (%/yr)	Reference
Deforestation and land clearing	Nigeria	Corn	22–36	Lal (1981)
	Nigeria	Corn	8–10	Hulugalle et al. (1984)
Simulated traffic	Nigeria	Corn	48–75	Kayombo and Lal (1986)
	Nigeria	Cowpea	38–57	Kayombo and Lal (1986)
	Nigeria	Soybean	25–65	Kayombo and Lal (1986)
	Nigeria	Cassava	38–47	Kayombo and Lal (1986)
	Pakistan	Wheat	7–38	Ishaq et al. (2001a)
	Pakistan	Sorghum	0–22	Ishaq et al. (2001a)
Decline in soil structure by tillage	Nigeria	Corn	8–23	Lal (1997)
	Nigeria	Corn	8–18	Lal (1984)

Once soil is compacted, the process is difficult and expensive to alleviate. Biological measures (including growing crops with tap root systems and encouraging the activity of earthworms and termites) are generally more effective and have longer-lasting effects in alleviating soil compaction than mechanical measures (such as sub-soiling involving deep plowing or chiseling). Sub-soiling can be an economically prohibitive undertaking even for large farmers in developed countries, let alone small-scale farmers with limited resources in developing countries. Furthermore, the adverse effects of compaction can persist for long periods, especially in clayey soils (Alakukku 2000; Wiermann and Horn 2000). Therefore, the best strategy is generally to adopt soil and crop management systems that prevent or minimize the risks of soil compaction in the first place. Different options for management of soil compaction are outlined in Figure 2.3. Two important preventive strategies are (a) the adoption of conservation tillage and mulch-farming techniques and (b) the reduction of axle loads. As above, the two basic alternatives for alleviating compaction are (a) biological measures and (b) mechanical techniques. If feasible, it is generally desirable to adopt conservation tillage to prevent or minimize the risk of soil compaction, and to adopt biological measures to alleviate soils that are already compacted. Since soil compaction accelerates soil erosion and vice versa, adoption of preventive measures for soil compaction would also reduce the risk of soil erosion.

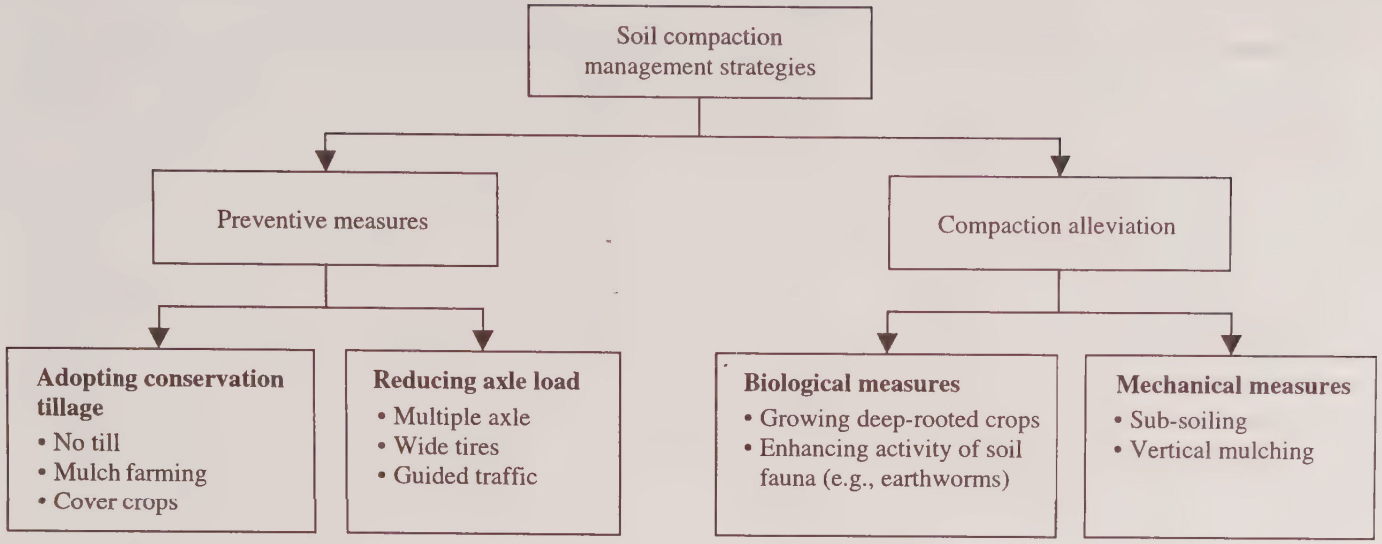

Figure 2.3 Strategies for management of soil compaction

CONCLUSIONS

Soil degradation and desertification pose serious challenges in the 21st century. Soil degradation, a biophysical process driven by socioeconomic and other anthropogenic factors, is a severe problem in South and Central Asia, Sub-Saharan Africa, and Latin America. Desertification, the degradation of soil and vegetation in arid and semi-arid regions, is also a major environmental problem in dry regions of Asia, Africa, and Latin America. Despite the severity of the problem, however, credible estimates of the extent and severity of soil degradation and desertification are scarce. The best available global estimates indicate that about 2.0 billion hectares are affected by soil degradation, and that about 3.6 billion hectares are affected by desertification. Principal processes affecting soil degradation include erosion by water and wind, salinization, fertility decline, and compaction. Desertification is driven primarily by over-grazing and inappropriate management practices.

Soil degradation and desertification have numerous on-site and off-site effects, chief among them being reduced productivity, pollution or contamination of natural waters, and emission of trace or greenhouse gases into the atmosphere. A number of studies have estimated productivity losses due to erosion at regional and global scales, but credible estimates of productivity losses due to soil compaction at regional and global scales are not available.

Soil compaction is caused by excessive vehicular traffic and treading by animals. The problem is severe in soils of the tropics and sub-tropics, which are characterized by predominantly low-activity clays, low swell–shrink capacity, and low soil organic matter content. Soil compaction is also severe in soils with slow internal drainage. It adversely affects plant growth and agronomic yield by restricting root growth and development, reducing soil water storage, and decreasing efficiency of water and nutrient use by plants. The magnitude of yield reduction is estimated to range from 20 to 50 percent, depending on soil type, crop, and tillage methods. Once soil is compacted, adverse effects may persist for several years, and alleviation is generally difficult and expensive. Therefore, it is important that farmers adopt preventive measures such as reduced traffic, reduced axle loads, and conservation tillage.

Soil degradation adversely affects food security, especially in developing countries where many resource-poor farmers are unable to use appropriate levels of fertilizers, manures, and other amendments. Adverse impacts are particularly evident in the low and stagnant crop yields and high malnutrition rates experienced in Sub-Saharan Africa. In North America, on the other hand, the effects of soil degradation on agronomic yields are much less severe because farmers are better able to adopt appropriate mitigating and restorative measures. In addition to its impacts on productivity and food security,

soil degradation also has severe environmental consequences, including water pollution, emission of greenhouse gases, and loss of biodiversity.

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